MMIC Low-Noise Amplifiers and Applications above 100 GHz

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The frequency range above 100 GHz is a fertile for next generation applications in telecommunications and radars as well as the fields of radio astronomy, Earth remote sensing , planetary exploration and millimeter-wave imagers. Working at these higher frequencies offers the advantages of broad available bandwidth, reduced aperture and instrument size, and a higher density of observable spectral lines. Advanced high frequency MMIC technology is uniquely suited to circuit fabrication above 100 GHz due to reduced parasitics and interconnections. Recent demonstrations in MMIC low noise amplifier and power amplifier technology above 100 GHz have enabled a new generation of instruments. In this paper we will discuss the development and performance of several first of a kind amplifiers for applications including microwave atmospheric sounding and radio astronomy.

The device performance necessary to achieve usable gain and noise figure for low noise amplifiers operating at frequencies between 100 to 200 GHz requires very high device transconductance above 1000 mS/mm, cutoff frequencies above 200 GHz and maximum oscillation frequencies above 400 GHz. To achieve usable gain and sufficient MMIC design margin, the device must exhibit a maximum available gain of 7-8 dB per stage up to 200 GHz. InGaAs/InAlAs/InP HEMTs are the only three terminal devices that have demonstrated performance at these levels.

In developing a MMIC process for this frequency range, three significant process enhancements were implemented on TRW's baseline 75 nm diameter InP HEMT process[1]. The first is the growth and design of pseudomorphic high indium composition InGaAs channels. Cutoff frequencies of 300 GHz have been achieved at the highest indium compositions greater than 70%. The 2nd process enhancement was the reduction of the gate length from 100 nm to 70 nm. 15-20% improvement in cutoff frequency and transconductance was observed in the shorter gate length devices compared to the baseline 100 nm devices with similar gate finger yield. The third area is the development of a 50 um thick substrate with very small through substrate grounding via holes. This process prevents substrate waveguide mode propagation and allows for minimal device source inductance to maximize device gain at high frequencies . TRW has established this enhanced MMIC process with an eye towards future production capability. Good MMIC yield and repeatability for this process on several wafer lots have already been demonstrated. The development of a robust InP MMIC process has been a critical key to the first-pass design success of the variety of MMIC amplifier designs shown in this paper.

In order to establish amplifier performance and optimize the designs, it is critical to obtain test data at these high frequencies. A series of waveguide frequency extenders for network analysis covering the range 50-220 GHz has been developed for this effort. In addition, wafer probes operating up to 220 GHz have been employed to obtain s-parameter data. Noise measurement capability has also been developed at frequencies as high as 200 GHz, as well as solid-state noise sources operating 180 GHz, which has enabled the first meaningful on-wafer noise measurements in this band. The data achieved from on-wafer measurements has also been duplicated in fixtured amplifier measurements.

A series of amplifiers has been demonstrated in the frequency range of 100 – 215 GHz. In the frequency range 85-110 GHz, a CPW low noise design uses four stages to achieve 20-25 dB gain and a module noise performance of 3-4 dB. Under cryogenic operation these amplifiers perform with 30-40K noise temperature (~0.5 dB NF). A three-stage microstrip amplifier covering the frequency range 112-120 GHz has 15 dB gain with a noise figure of 4-5 dB (Figure 1). A three-stage microstrip amplifier design demonstrated 14 dB gain and a noise figure of 7 dB 165 GHz to 190 GHz (Figure 2). Two amplifiers were cascaded to achieve 20-25 dB gain from 170-190 GHz with 7.5 dB noise figure average across the band (Fig. 3). A 6-stage CPW design covering the frequency range 160-215 GHz has 20 dB average gain with a measured module noise figure of 8 dB at 170 GHz (Figure 4,5). The measured 15 dB gain at 215 GHz is the highest frequency gain amplifier demonstrated to date. Further state-of-art amplifer demonstrations are shown in Table 1.

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[1] **R. Lai** et al. "A High Volume 0.1 um InP HEMT Production Process for Applications from 2 GHz to 200 GHz", Proceedings from 1999 GaAs MANTECH Conference, Vancouver, Canada

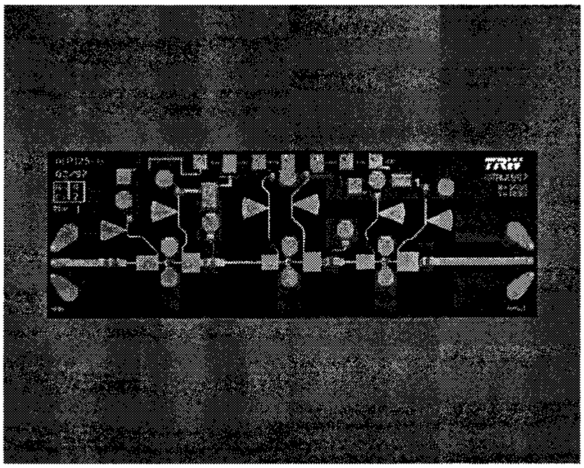


Figure 1. Photo of 3-stage 112-120 GHz MMIC amplifier amplifier

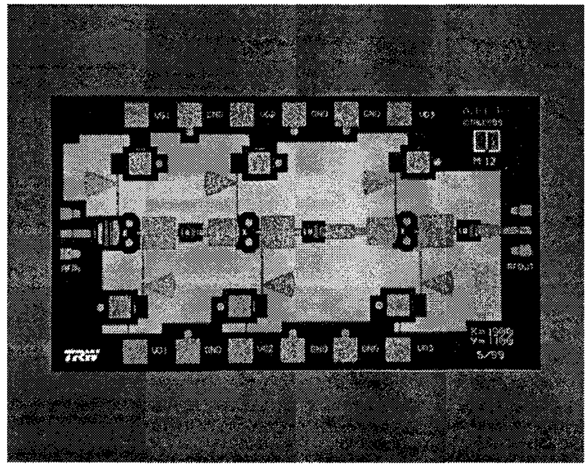
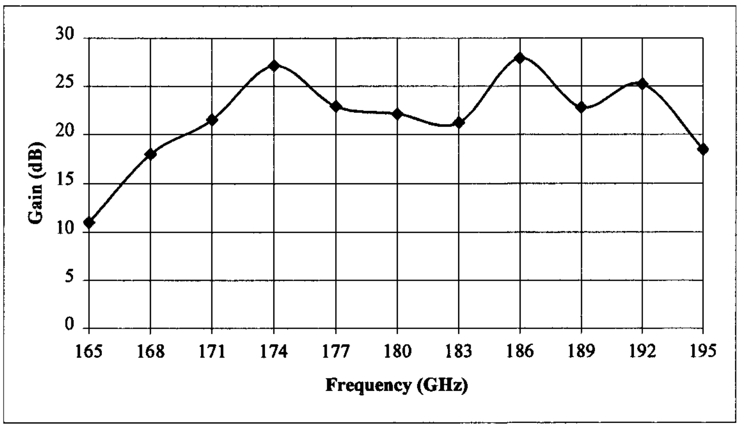


Figure 2. Photo of 3-stage 165-190 GHz MMIC



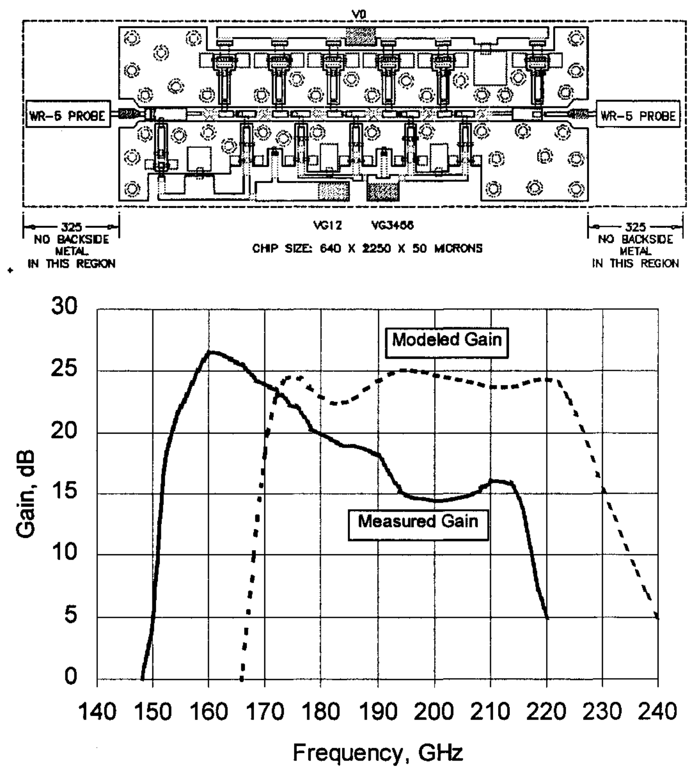


Figure 4, 5 Circuit schematic and gain response for 160-215 GHz 6-stage coplanar LNA MMIC

Frequency	Description	Performance
85-115 GHz	4-stage CPW design	3 dB NF, 0.5 dB NF cryogenic operation
112-120 GHz	3-stage Microstrip	4-5 dB NF, 15 dB gain
140 GHz	2-stage Microstrip	6 dB NF, 9 dB gain
151-155 GHz	3-stage Microstrip	5 dB NF, 8-10 dB gain
165-190 GHz	3-stage Microstrip	7 dB NF, 12-15 dB gain
160-215 GHz	6-stage CPW	8 dB NF(at 170 GHz), 15-25 dB gain

Figure 6. List of demonstrated state-of-art MMIC amplifiers from 100 GHz to 215 GHz